RECENT TIMING ACTIVITIES AT THE U.S. NAVAL RESEARCH LABORATORY

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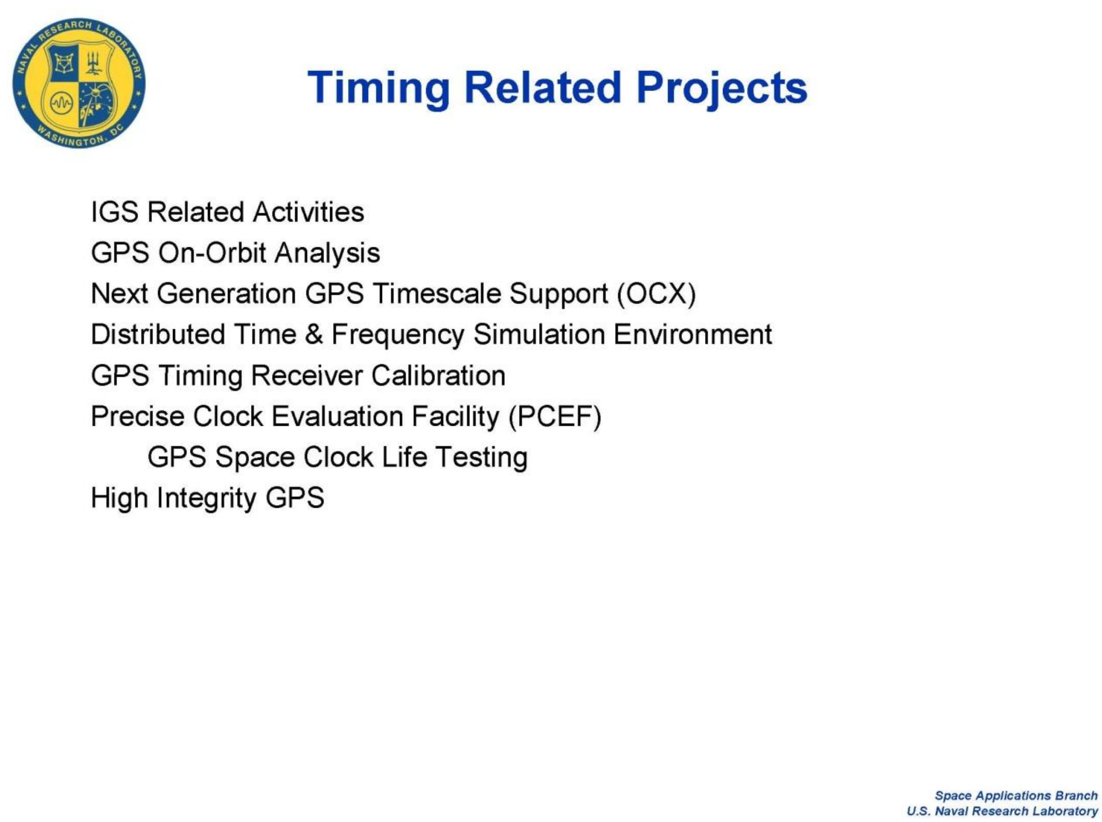
Abstract

The U.S. Naval Research Laboratory has a number of ongoing time and frequency programs. This paper provides an overview of work currently being done. The programs include GPS clock life testing and on-orbit analysis, Distributed Time and Frequency Sustems, and iGPS. An update on UTC (NRL) is also presented.



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NRL IGS Activities

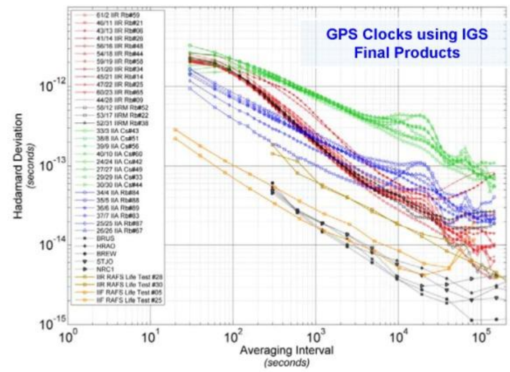
The International GNSS Service (IGS) is a federation of over 200 agencies

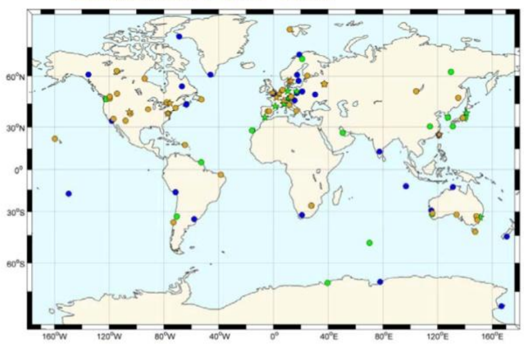
- **Produces standards and products for application in the geosciences.**

NRL chairs the IGS Clock Products Working Group (CPWG)

Primary responsibility of the CPWG is the production of the IGS timescales

- **Rapid IGS clock products are aligned to IGRT daily**
- **Final IGS clock products are aligned to IGST weekly**
- **Allows dissemination of IGS time (1×10^{-15} @ 1 d)**
- **Dissemination of UTC < 50 ns**





IGS timescales are generated from a distributed network of clocks

- Kalman filter implementation
- dynamically weighted clocks
- driven mostly by H-Masers
- IIR Rb clocks ~ 1% each

Tracking Station Clocks:

- H-masers (57)
- cesiums (32)
- rubidiums (30)
- ☆ time lab stations (26)

Satellite Clocks:

- cesiums (7)
- rubidiums (24)

UT1/LOD Analysis

New Kalman filter for optimally combining VLBI UT1 & GPS LOD

- New filter produces best UT1/LOD as compared to all other similar products by multiple measures including comparison with independent Atmospheric and Oceanic Angular Momentum Data
- Used to support recent U.S. NRC Study
- Code made available

IERS combinations do not use VLBI UT1 & GPS LOD inputs optimally!

- fidelity of high-frequency geodetic measurements is degraded

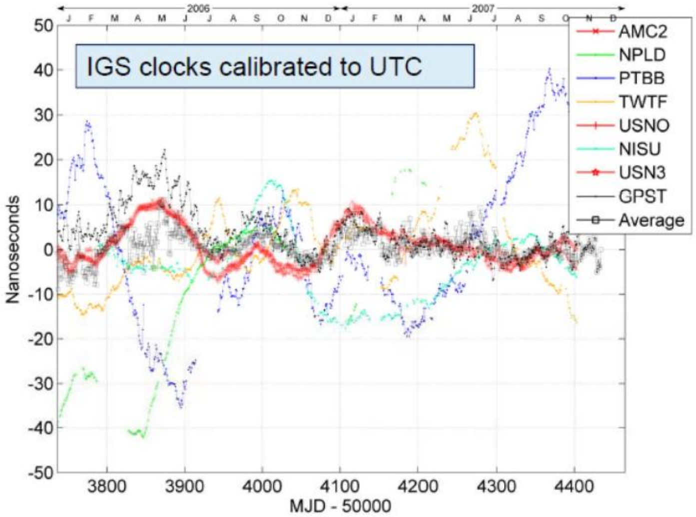
Main Issues: VLBI UT1 & GPS LOD combinations must recognize & mitigate systematic errors

- UT1 from VLBI Intensives has serious baseline- & time-dependent errors
- UT1 from weak VLBI sessions should be rejected
- GPS LODs have bias & harmonic errors that should be modeled

Motivation: IGS real-time orbit predictions require better EOP predictions

- UT1 prediction errors (= RZ rotation errors) dominate real-time performance
- polar motion prediction errors are also significant

New Time Scale – Tie to UTC



Current Version relies on GPS Time for Reference to UTC

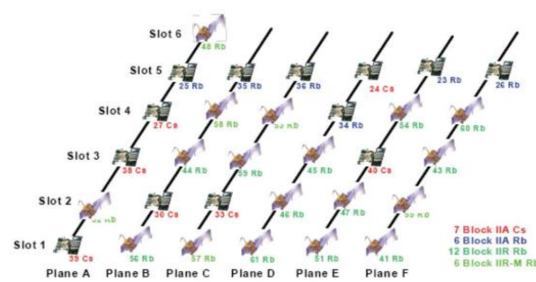
Multiple Stations collocated at Timing Centers will provide a better quality and robust link to UTC, relatively calibrated to UTC through Circular T

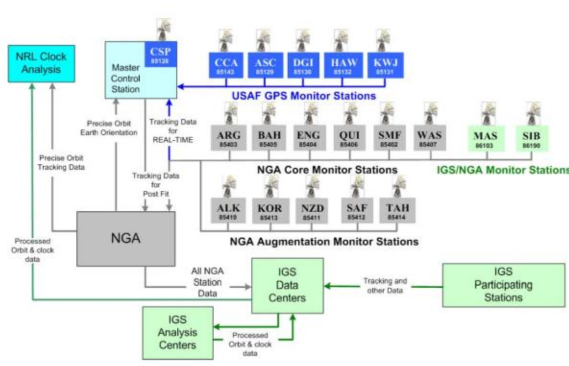
Stability of the average of these clocks suggest a steering time constant of about 70 days

GPS On-Orbit Analysis

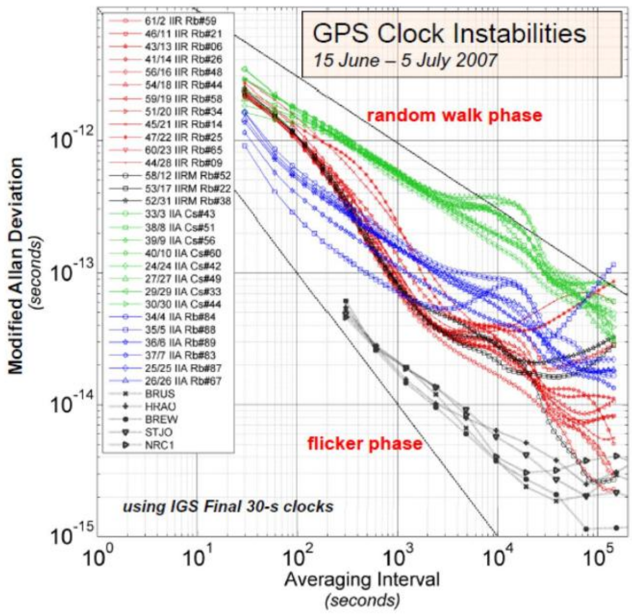
- On Line Databases of all SV and MS tracking data
- Precise measurement data in system and external
- Characterization of SV and MS clocks
- Anomaly investigation
- Tuning of Filter Q's

Data Source	Data Type	Description
NGA	15-minute phase	SV clock offsets relative to DOD Master Clock
NGA	15-minute phase	GPS MS clock offsets relative to DOD Master Clock
IGS	5-minute phase	SV clock offsets relative to IGS time scale
IGS	5-minute phase	IGS GPS ground clock offsets relative to IGS time scale
IGS	5-minute phase	IGS timescale reference data
NRL analytical results	SV clock discontinuity	SV clock phase, frequency, and drift discontinuities magnitude and epoch
NRL analytical results	MS clock discontinuity	MS clock phase, and frequency discontinuities magnitude and epoch
GPS MCS	Time period	SV clock operating periods
GPS MCS	Time period	SV operating periods
GPS MCS	Time period	SV position in the GPS constellation
NRL computed	SV eclipse periods	SV periods of time when the earth shadows a portion of the orbit from the sun
NGA	SV x,y,z trajectory	Precise post-fit SV ephemerides
IGS	SV x,y,z trajectory	Precise post-fit SV ephemerides
IGS	GPS broadcast data	Predicted orbit and clock transmitted in the GPS signal





On-Orbit Performance



- IIA cesiums
  - poorest overall stability
  - behave mostly as random walk phase noise
  - MDEV power-law slope -1/2
  - excess deviations near 13,600 s
- IIA rubidiums
  - similar to Cs clocks but much more stable
  - flicker phase component for intervals < 100 s
  - also with excess near 13,600 s
- IIR & IIR-M rubidiums
  - newer generation clocks less stable than IIA Rb up to 1000 s
  - complex high-frequency behavior due to onboard Time Keeping System (TKS)
  - some excess near 13,600 s

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Next Generation GPS Timescale

CONTEXT/PROBLEM:

- **GPS system functionality relies on stable satellite clocks & the ability to predict them well; individual clock prediction in turn requires a stable reference timescale**
- **Next Generation GPS operational ground control segment (OCX) now being designed**
  - **NRL support requested by JPL**

Goal / NRL Approach:

- **Develop a more stable ensemble timescale**
- **Leverage existing Kalman filter approaches but with improved clock modeling**
- **Algorithm developed under ONR funded project**
- **NRL providing algorithm/code development/testing/consultation**

Challenges:

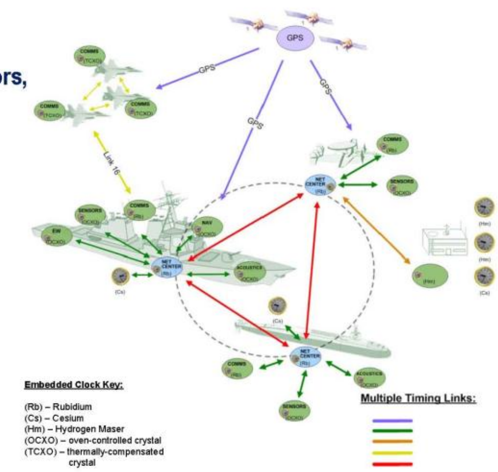
- **Intended for operational use**
- **Must be highly robust against individual clock failures**
- **Must be adaptive in its determination of model parameters**

Distributed Timekeeping

- Current proliferation of single-source (GPS-centric) timekeeping
- A new approach that *inter-compares* & *combines* existing embedded timing signals:
  - would enable in-situ determination of performance,
  - improve & make more robust the timekeeping (holdover) capability,
  - provide synchronization,
  - provide integrity feedback to individual systems/sensors,
  - limit single-source failures & vulnerabilities

Requires new theory & algorithms for combining timing signals of very different type & quality through widely varying links

- Clocks perform very differently:
  - in same & different environments
  - over different periods of time (scales)

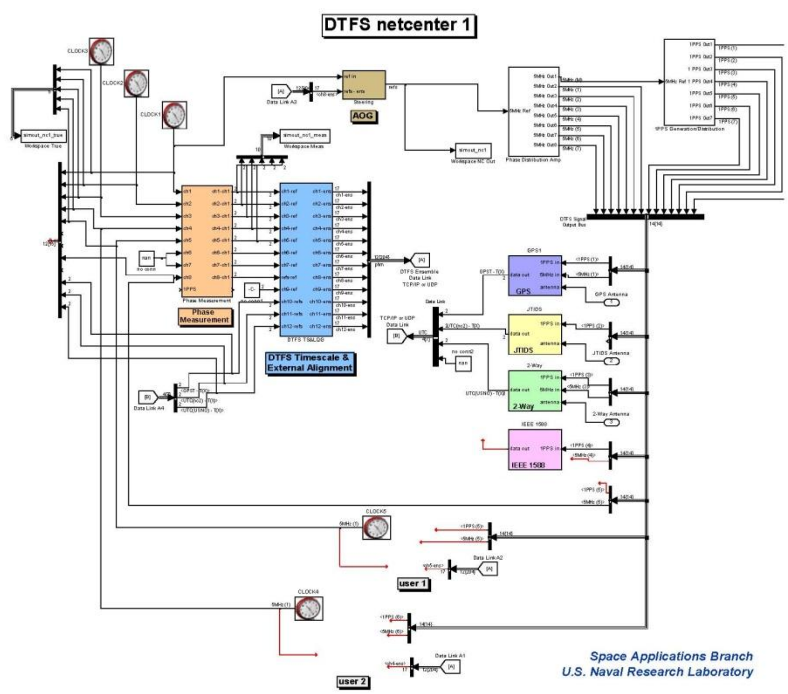


DTFS Simulation Environment

Distributed Time and Frequency Simulink simulation environment

Used to model distributed common time/frequency architectures

Includes ensemble clock models, timescale algorithms, control loops, and multiple external links



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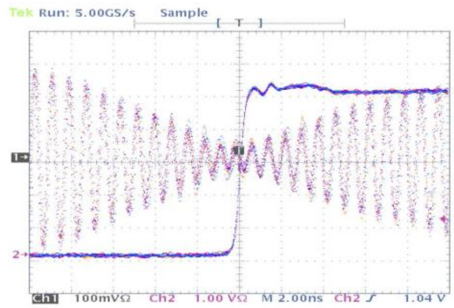
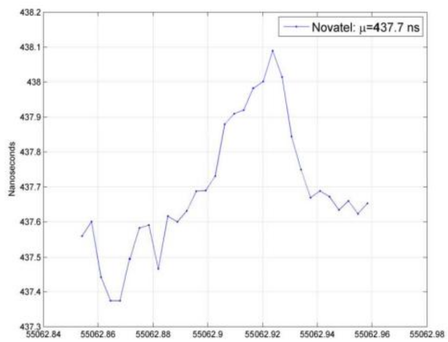
GPS Timing Receiver Calibration





Simulator Calibration

Date/time	Simulator L1 Bias	Simulator L2 Bias	Corrected L1 Receiver Offset	Comments
54222.5	0	4	20.2 nsec	
54236	1	4	22.5 nsec	
54237	0	3	21.1 nsec	

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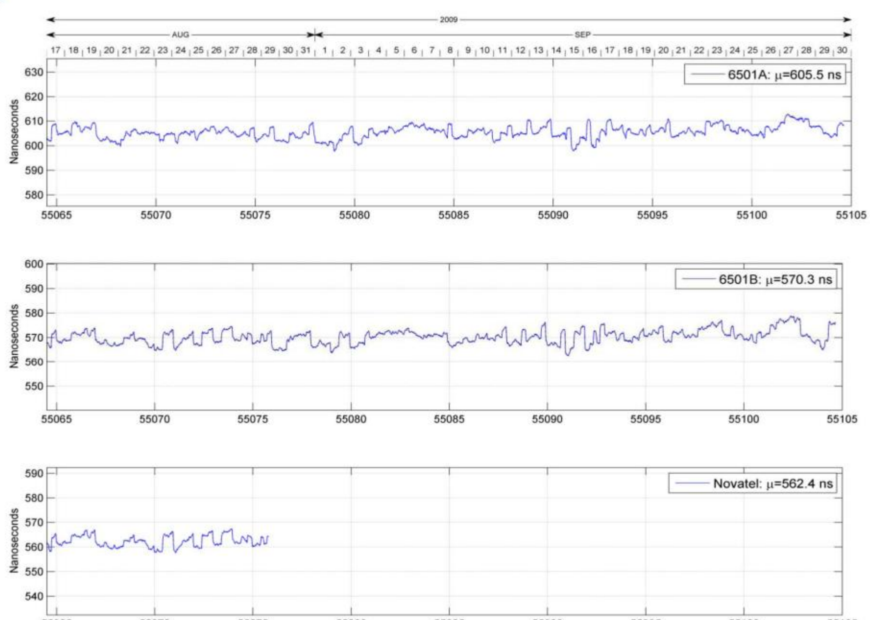
GPS Timing Receiver Calibration



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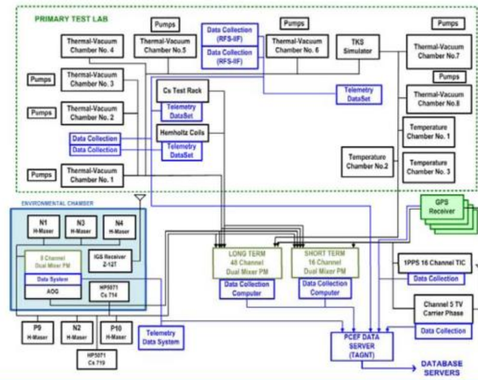
Precise Clock Evaluation Facility (PCEF)

Multi-Channel Measurement Systems

Precise Frequency Dissemination Systems

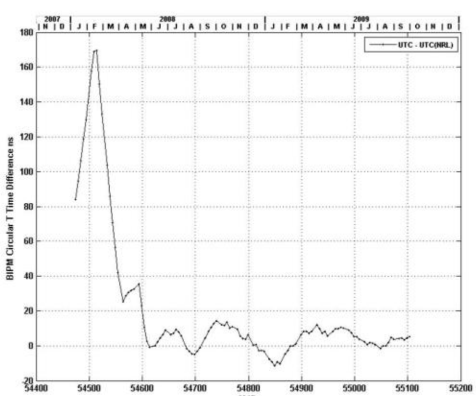


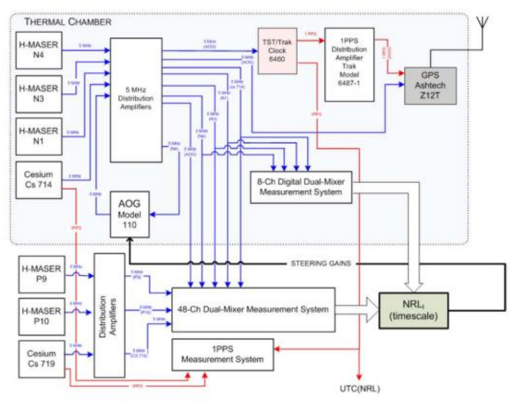
- **Precise and Accurate Time and Frequency References**
- **Maintain realization of Universal Coordinated Time, UTC(NRL)**
- **Multiple precise dual mixer phase comparison systems**
- **Automated data collection and archival systems**
- **Precise time/frequency transfer and dissemination systems**
- **Multichannel 1PPS evaluation system**

UTC (NRL)

Purpose is to support Navy/NRL time & frequency research activities

Unique tool for investigation of time scale algorithms and techniques





Began submitting clock data to BIPM in September '07 under test/evaluation

Official submissions began in January 2008

Space Clock Extended Life Tests

BLOCK IIR RAFS LIFE TEST

1997 - 2005

BLOCK IIF CESIUM EXTENDED TEST

2004 – Interrupted in 2006

BLOCK IIF RFS LIFE TEST

2008 – In process

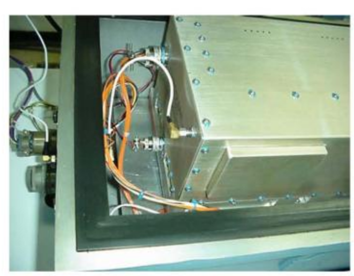
- Space-Like Environment (vacuum & temperature)
- Installation in test chambers duplicates mounting in SV
- Continuous Operation for a minimum of three years

- Validates SV Telemetry and Control Interface
- Validates operation prior to actual flight in operational SV
- High precision performance evaluation

GPS Block IIF DCBFS Life Test

Began in August 2004

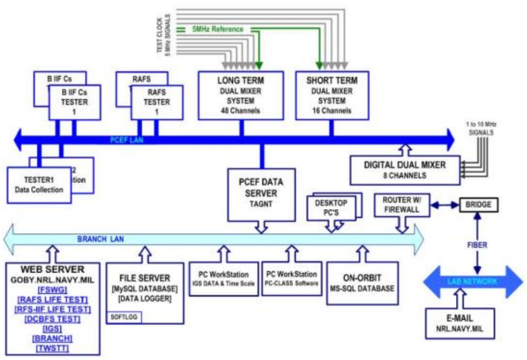
Interrupted in 2006



GPS Block IIF RFS Life Test

Two GPS IIF production clocks, No 5 and 25 are under test

Test configuration improved over that used in prior tests.



Life Test Data Flow

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High Integrity GPS (iGPS)
Operational Concept